Cellular Respiration

2 Goals of cellular Respiration

1. Break down sugars so they can be changed into other usable parts.
2. Release the energy stored in sugars to make ATP.

Q: Why do plants need this if they make ATP during Photosynthesis???

A: The ATP made during Photosynthesis is USED up during photosynthesis!

- Plants can make all the sugar they want but it is useless unless they do something with it.

Most Eukaryotes carry out Cellular Respiration.

3 Phases of Cellular Respiration

1. Glycolysis
2. Krebs Cycle
3. Oxidative Phosphorylation

EQUATION:

$$6O_2 + C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O$$

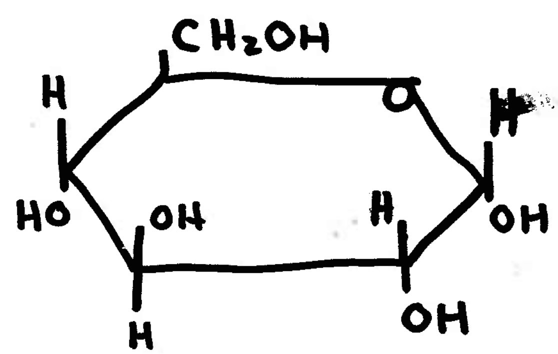
The "opposite" of Photosynthesis.

1. Reactions of Glycolysis

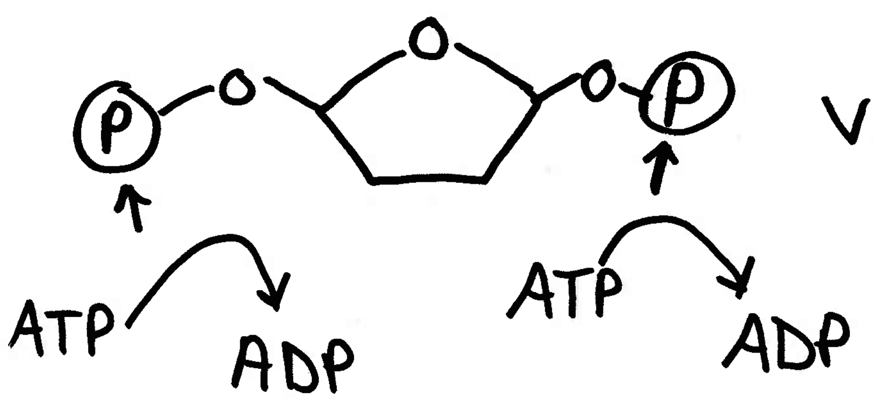
A. Glycolysis means "split sugar"

① Start with ONE molecule of GLUCOSE

$C_6H_{12}O_6$



② 2 ATP each transfer a phosphate to Glucose



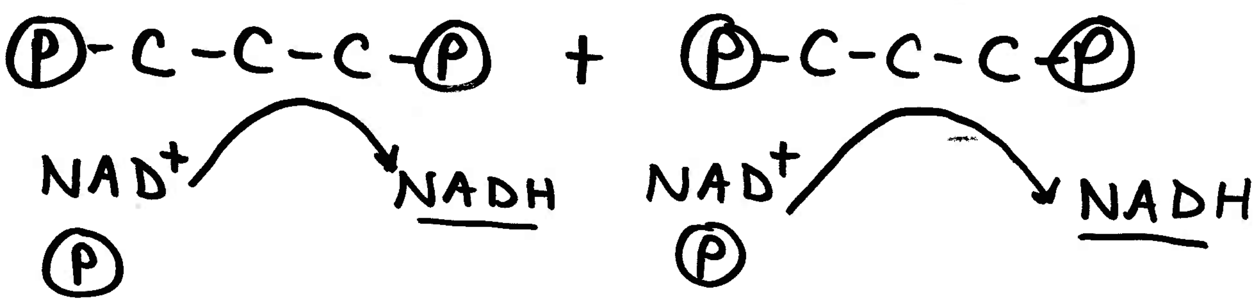
VERY ENERGETIC!

−2 ATP

③ Now the molecule "Splits" and the result is <u>TWO</u> 3-Carbon molecules, each with a phosphate group.

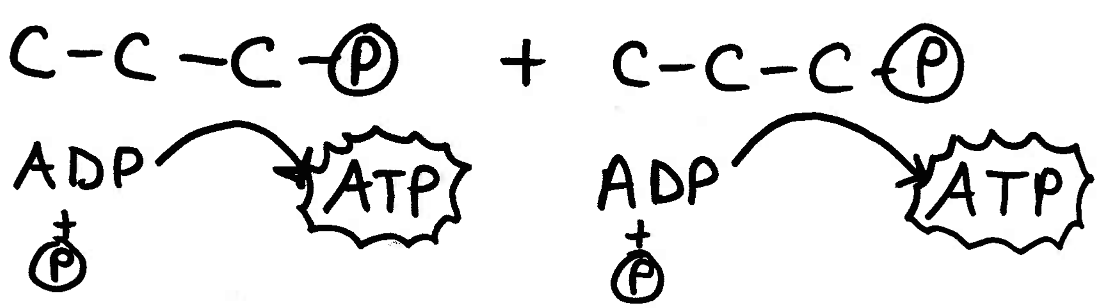
C-C-C-Ⓟ + C-C-C-Ⓟ

④ For <u>EACH</u> molecule, NAD^+ gets reduced and oxidizes our 2 sugars. A phosphate group is attached also.



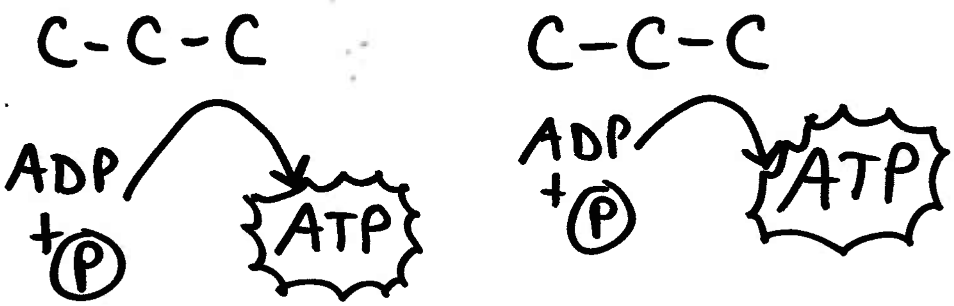
= 2 NADH

⑤ An enzyme takes off the Ⓟ of each molecule and attaches it to ADP = 2 ATP



= 2 ATP

⑥ Another enzyme removes the other phosphate from the sugar molecules. Many rearrangements to the "sugar" happened during these processes. The molecule we are left with is called <u>PYRUVATE</u>. 2 ATP also were made.



2 Pyruvate + 2 ATP

Overview of Glycolysis

1 Glucose → −2 ATP → +2 ATP → +2 ATP

NET= ______ ATP from Glycolysis.

Product molecule = 2 ______

Other Products = 2 ______

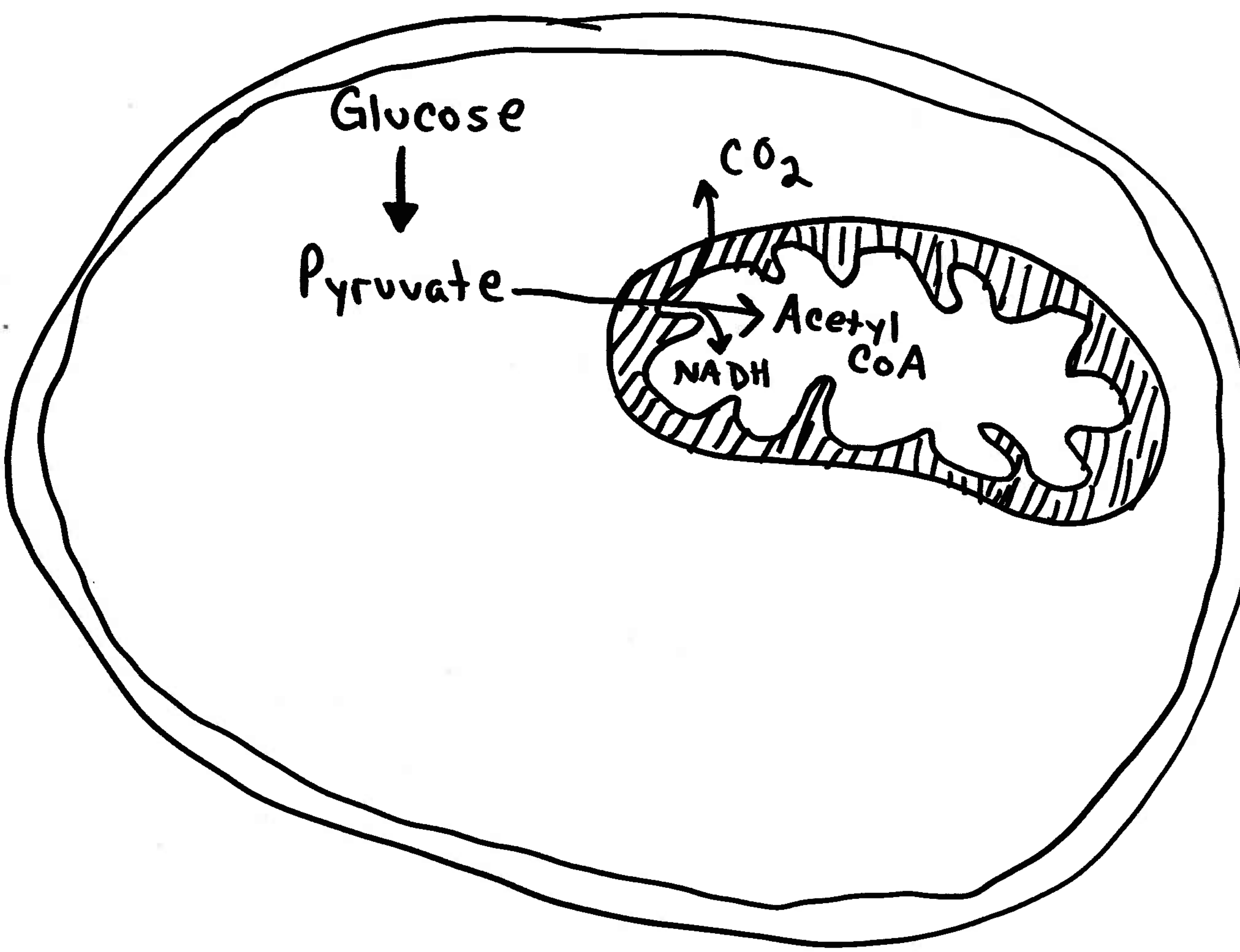
NOW WHAT???

Glycolysis happens in the <u>CYTOPLASM</u>.

- Pyruvate is transported into the <u>mitochondria</u> where the next 2 phases happen.

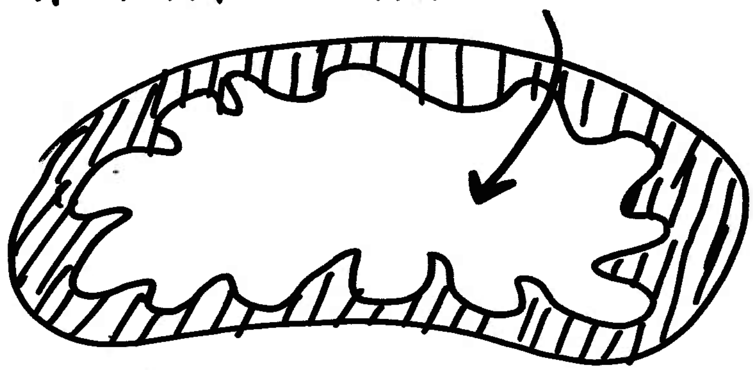
- The Krebs cycle uses <u>Acetyl CoA</u>.

* Steps not required (to know) but realize pyruvate MUST be converted and that NADH is made in the process. *



2. The Krebs Cycle

Location: Mitochondrial Matrix



① C–C–C–C + C–C–[CoA] → C–C–C–C–C–C

(Oxaloacetate) (Acetyl CoA) (Citrate)

Acetyl CoA joins Oxaloacetate, the CoA is removed.

② C–C–C–C–C–C → (CoA) C–C–C–C–[CoA]

→ $2CO_2$

$2NAD^+$ → $2NADH$

Enzymes <u>remove CO_2</u> and the energy released is used to <u>make NADH</u>. CoA is added

③ C–C–C–C–[CoA] → [CoA] C–C–C–C

ADP + Ⓟ → ATP

CoA is removed and the energy is used to form ATP.

(4) C–C–C–C → C–C–C–C (Oxaloacetate)

NAD^+ → NADH

FAD → $FADH_2$

Many complex rearrangements occur. NAD^+ and a similar molecule, FAD, get reduced to form NADH and $FADH_2$. Oxaloacetate is regenerated.

Each of these steps happen for each original input of Acetyl-CoA.

- Inventory from Krebs Cycle

For each Pyruvate =

- 2 NADH (Transport into Mitochondria + forming Acetyl-CoA)
- 2 ATP, 6 NADH, 2 $FADH_2$ } Krebs Cycle

So far...

	ATP	NADH/$FADH_2$
Glycolysis	2 ATP	2 NADH
Krebs Cycle	2 ATP	2 NADH (transport) 6 NADH / 2 $FADH_2$

Totals = <u>4 ATP</u> <u>10 NADH</u> & <u>2 $FADH_2$</u>

- 4 ATP is really great and all, but it's really not a lot!
- What's with the NADH?

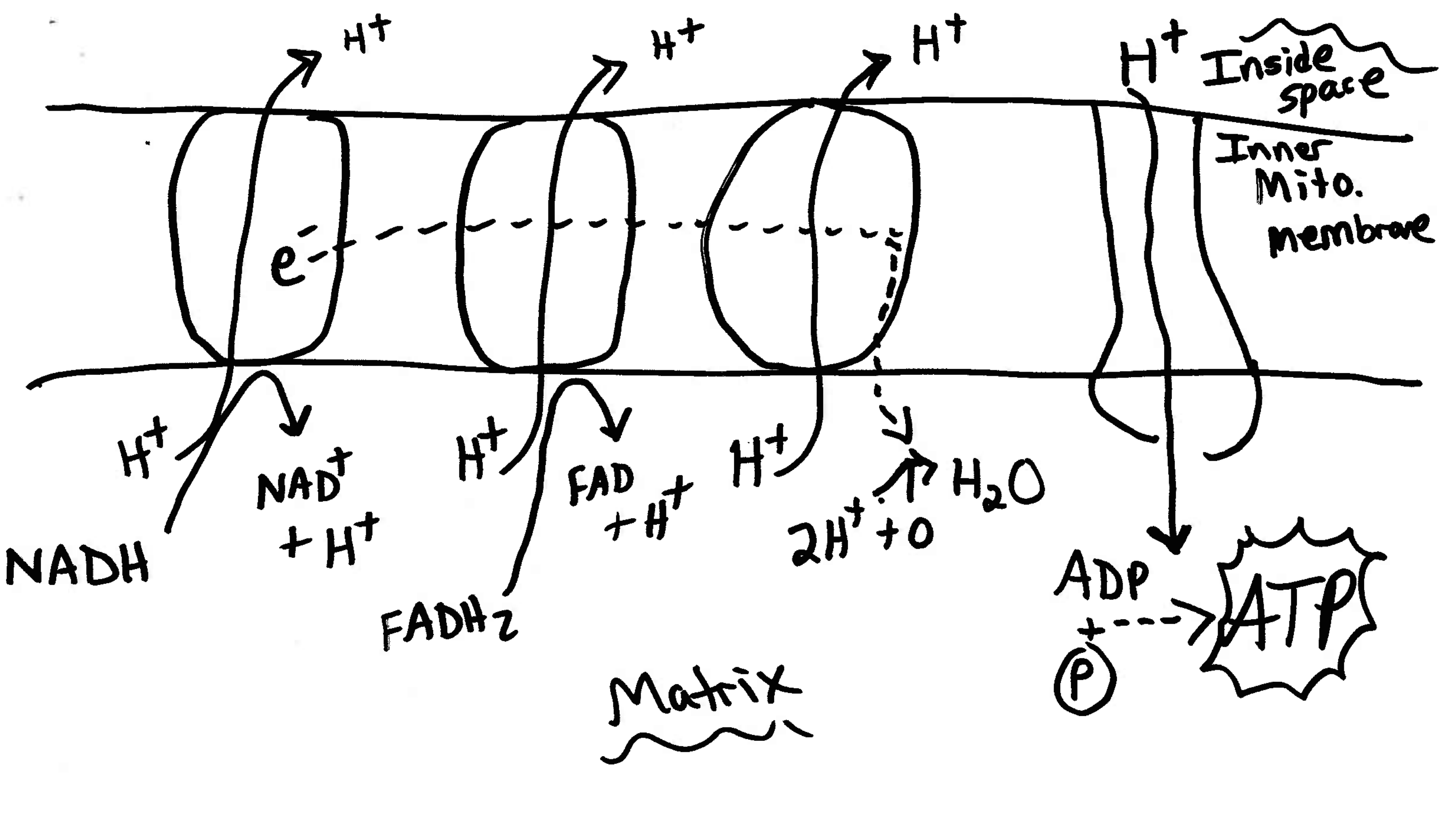
Remember that NADPH was an electron carrier.

NADH is similar! ($FADH_2$ Also)

The 3rd and final step puts all the electron carriers to work, similar to the LDR's did.

③ Oxidative Phosphorylation

- Oxidative phosphorylation uses the electrons from NADH/$FADH_2$ to generate a proton gradient.
- Every NADH can provide energy to pump 3 H^+ from the matrix into the intermembrane space. ($FADH_2$ can pump 2 H^+).
- The H^+ builds up causing a disequilibrium. They can "escape" through <u>ATP synthase</u>.
- This is similar to the one from photosynthesis, but it is more efficient! There is a 1:1 ratio for H^+ pumped to ATP created.



- The whole process is accomplished using the proton gradient = CHEMIOSMOSIS.
- Note that the final destination for electrons is inside the bonds of a water molecule.
- Water is made of OXYGEN and hydrogen.
- Because <u>Oxygen</u> is a final electron acceptor this form of cellular respiration is more specifically called AEROBIC Respiration.

Many Bacteria live in <u>anaerobic</u> places but use a similar process. Many use Sulfur as the final electron acceptor.

Totals from Cellular Respiration

2 ATP – Glycolysis

2 ATP – Krebs Cycle

34 ATP – Oxidative Phosphorylation

---

38 ATP From <u>1 Glucose molecule</u>

Related Processes

A. Fermentation (NADH gives electrons to an organic molecule)

- Happens when Oxygen is not present and as a "quick fix" for ATP.

① Lactic Acid Fermentation

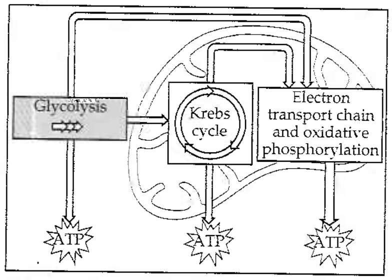
- Pyruvate is converted to Lactic Acid
- Makes 2 ATP
- Happens in muscle cells (No oxygen!) Causes cramps!

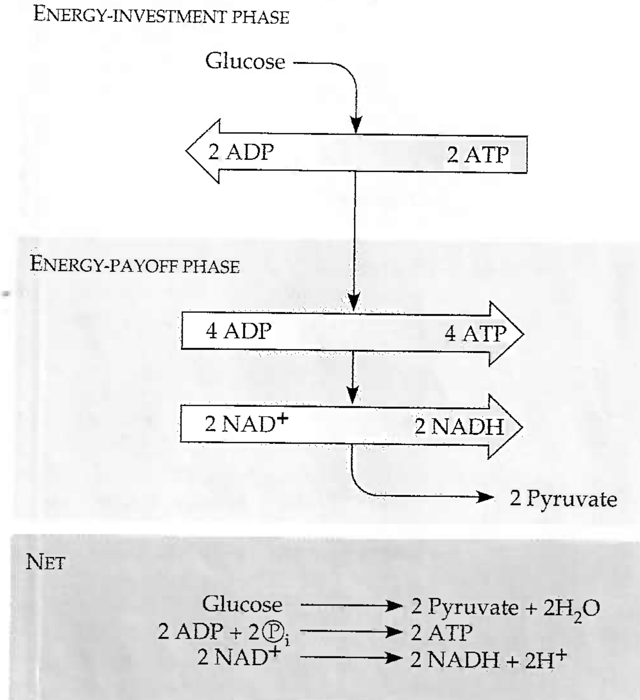
② Alcoholic Fermentation

- Pyruvate is converted to Ethanol
- Makes 2 ATP
- Yeasts use this and Industries depend on it for beer + wine making.
  - Releases CO_2 (Bubbles in beer and causes bread to rise)

Glycolysis Diagram

Note the location!



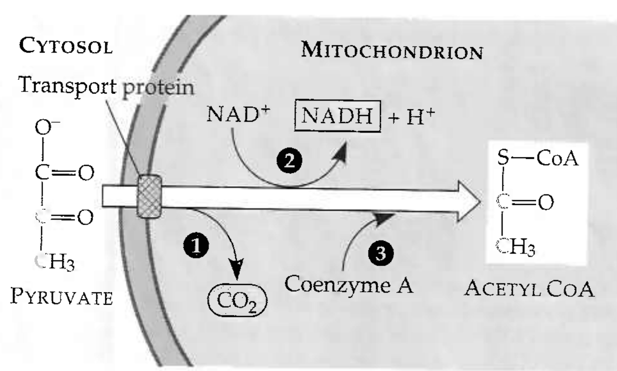


Products per Glucose =
2 Pyruvate
2 ATP
2 NADH, 2 H+

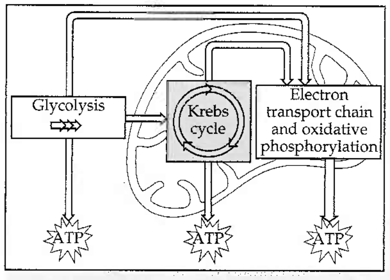
FIGURE 9.8 ▪ The energy input and output of glycolysis.

Transporting Pyruvate into the mitochondria

Changing pyruvate into Acetyl-CoA =
Releases 2 carbon dioxide
Forms 2 NADH and 2 H+
(accounts for each pyruvate)



9.3 **FIGURE 9.10 ▪ Conversion of pyruvate to acetyl CoA, the junction between glycolysis and the Krebs cycle.** A protein built into the inner mitochondrial membrane translocates pyruvate from the cytosol into the mitochondrial matrix. Then ① the carboxyl group of pyruvate, already fully oxidized, is removed as a CO_2 molecule, which diffuses out of the cell. ② The remaining two-carbon fragment is oxidized while NAD^+ is reduced to NADH. ③ Finally, the two-carbon acetyl group is attached to coenzyme A (CoA). The coenzyme has a sulfur atom, which attaches to the acetyl fragment by an unstable bond. This activates the acetyl group for the first reaction of the Krebs cycle.

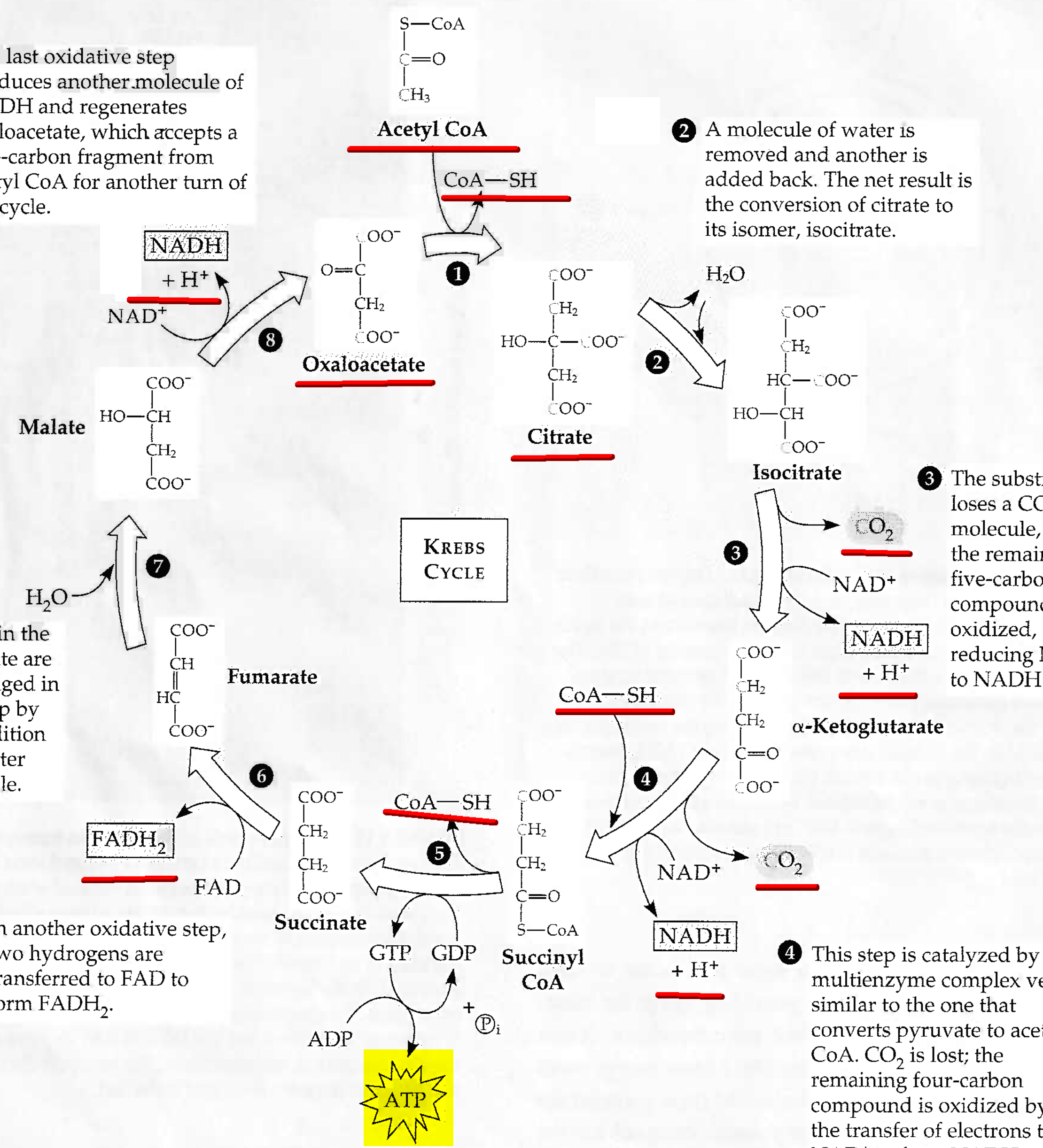


Krebs Cycle Diagram. Note the location. Don't memorize names unless I specified them in the notes!
Starts out with = 2 Acetyl-CoA
Releases 4 carbon dioxide
Forms 2 ATP, 2 FADH2, and 6 NADH

——— = Important step or name!!!

Note: Diagram shows only ONE Acetyl-CoA input!!!!

1 Acetyl CoA adds its two-carbon fragment to oxaloacetate, a four-carbon compound. The unstable bond of acetyl CoA is broken as oxaloacetate displaces the coenzyme and attaches to the acetyl group. The product is the six-carbon citrate. CoA is then free to prime another two-carbon fragment derived from pyruvate. Notice that oxaloacetate is regenerated by the last step of the cycle.



2 A molecule of water is removed and another is added back. The net result is the conversion of citrate to its isomer, isocitrate.

3 The substrate loses a CO_2 molecule, and the remaining five-carbon compound is oxidized, reducing NAD^+ to NADH.

4 This step is catalyzed by a multienzyme complex very similar to the one that converts pyruvate to acetyl CoA. CO_2 is lost; the remaining four-carbon compound is oxidized by the transfer of electrons to NAD^+ to form NADH, and is then attached to coenzyme A by an unstable bond.

5 Substrate-level phosphorylation occurs in this step. CoA is displaced by a phosphate group, which is then transferred to GDP to form guanosine triphosphate (GTP). GTP is similar to ATP, which is formed when GTP donates a phosphate group to ADP.

6 In another oxidative step, two hydrogens are transferred to FAD to form $FADH_2$.

7 Bonds in the substrate are rearranged in this step by the addition of a water molecule.

8 The last oxidative step produces another molecule of NADH and regenerates oxaloacetate, which accepts a two-carbon fragment from acetyl CoA for another turn of the cycle.

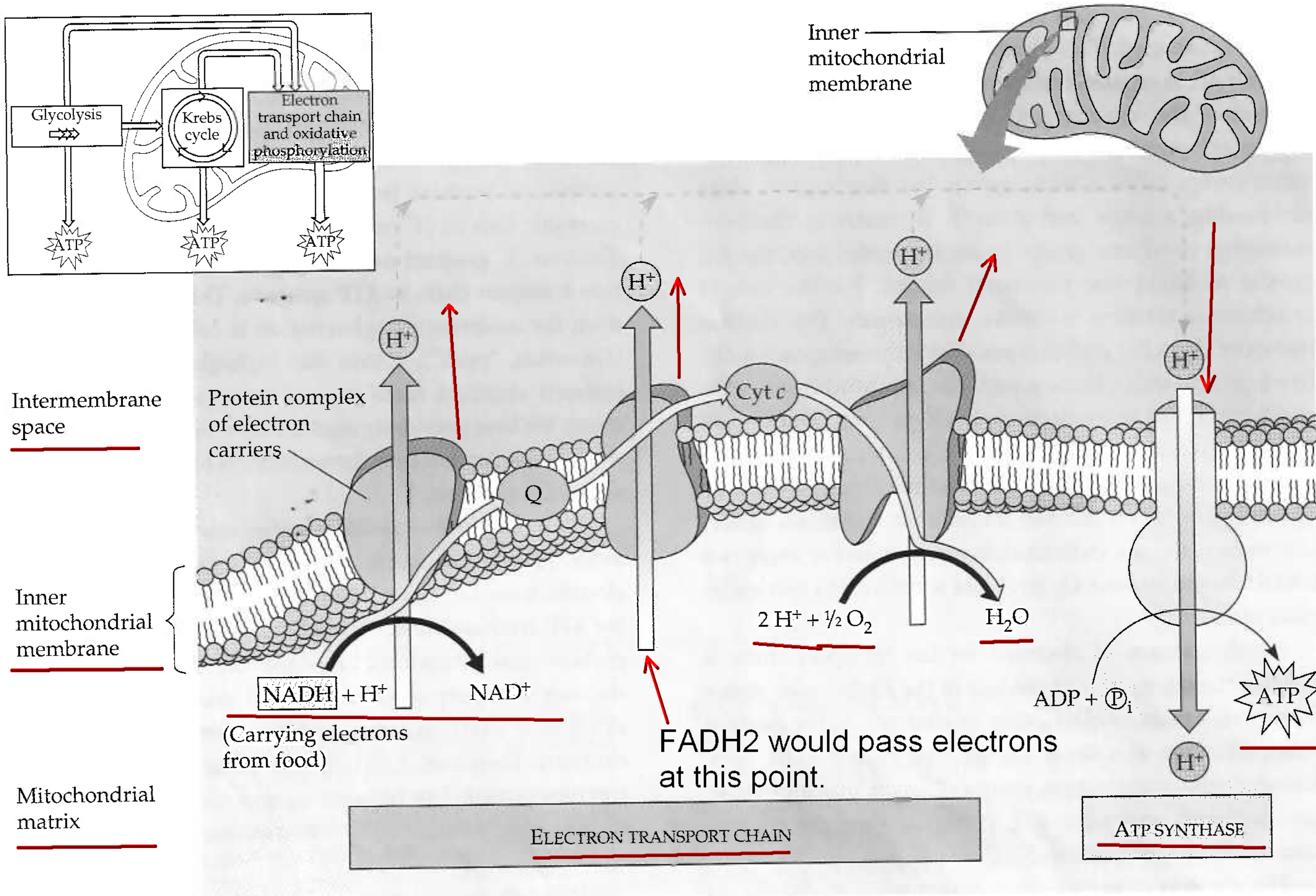


FIGURE 9.15 ▪ Chemiosmosis: How the mitochondrial membrane couples electron transport to oxidative phosphorylation. NADH shuttles high-energy electrons extracted from food during glycolysis and the Krebs cycle to an electron transport chain, which is built into the inner mitochondrial membrane. The gold arrow in this diagram traces the transport of electrons, which pass to oxygen at the "downhill" end of the chain to form water. Most of the cytochromes and other electron carriers of the chain (see FIGURE 9.13) are collected into three complexes, each represented here by a purple blob embedded in the membrane. Two mobile carriers, ubiquinone (Q) and cytochrome *c*, move rapidly along the membrane, ferrying electrons between the three large complexes. As each complex of the chain accepts and then donates electrons, it pumps hydrogen ions (protons) from the mitochondrial matrix into the intermembrane space (magenta arrows trace H^+ transport). Thus, chemical energy harvested from food is transformed into a proton-motive force, a gradient of H^+ across the membrane. The hydrogen ions complete their circuit by flowing down their gradient through an H^+ channel in an ATP synthase, another protein complex built into the membrane. The ATP synthase harnesses the proton-motive force to phosphorylate ADP, forming ATP. (This is called oxidative phosphorylation because it is driven by the exergonic transfer of electrons from food to oxygen.) This mechanism for energy coupling—the use of an H^+ gradient (proton-motive force) to transfer energy from redox reactions to cellular work (ATP synthesis, in this case)—is called chemiosmosis.

9.4

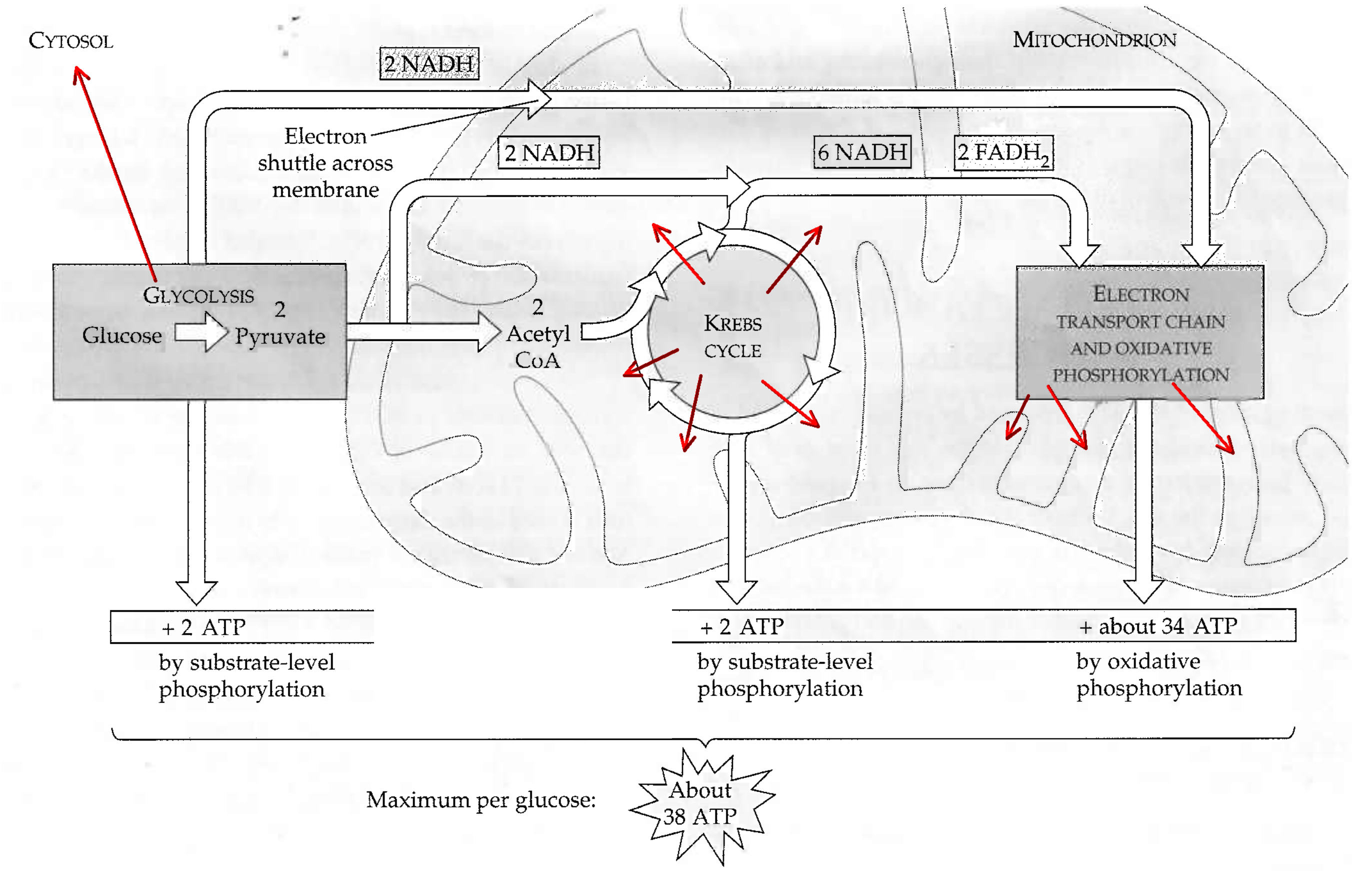
Oxidative Phosphorylation Diagram
Note the locations for events.
Notice that each NADH can drive 3 H+ across membrane.
Each H+ = Energy to power ATP synthase, making 1 ATP.
10 NADH = 30 ATP
Notice that FADH2 enters after the first proton pump, so can only drive 2 H+ across membrane.
2 FADH = 4 ATP

34 ATP from oxidative phosphorylation

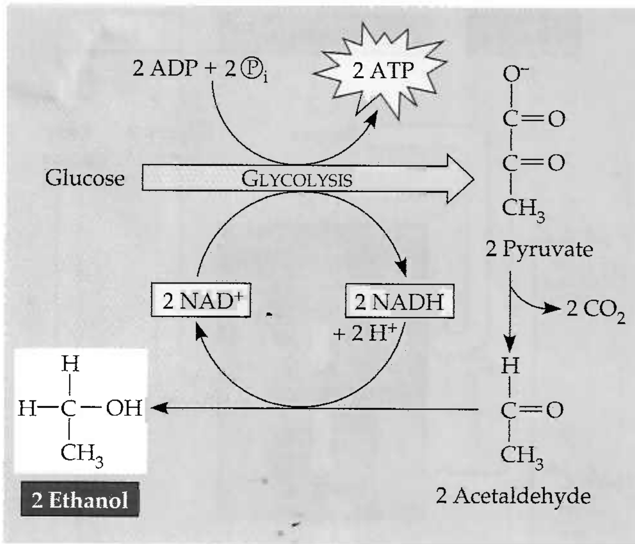
Overview of ATP totals from Cellular Respiration

NOTICE THE LOCATIONS!!!

Glycolysis = Cytosol
Krebs Cycle = Mitochondrial Matrix (Goopy fluid inside mitochondria)
Ox. Phos. = Inner Mitochondrial Membrane (Electron transport chains require membranes!)

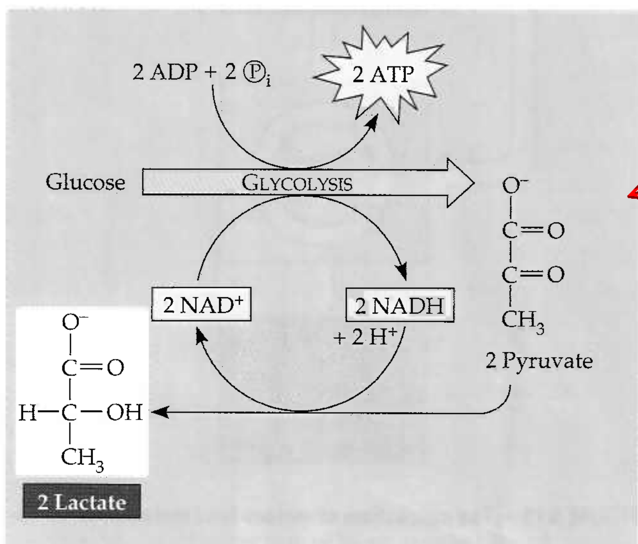


Fermentation Diagrams



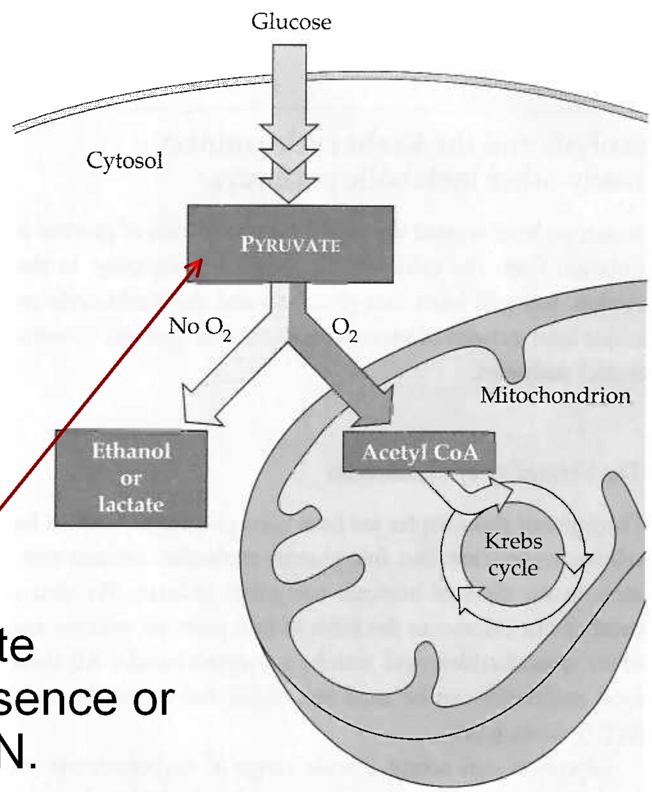
(a) Alcohol fermentation

Alcohol Fermentation



(b) Lactic acid fermentation

Lactic Acid Fermentation



The "fate" of pyruvate depends on the presence or absence of OXYGEN.

What are you responsible for knowing?

1. Locations for processes
2. Reactants & Products for each process
3. ATP used/gained for each process and in total
4. How oxygen affects the metabolic path used
5. Molecule names only if mentioned in notes (not diagrams)
6. Relationship(s) between processes